

PB88-249578

FLEX: An Expert System to Assess  
Flexible Membrane Liner Materials

(U.S.) Environmental Protection Agency  
Cincinnati, OH

Aug 88



U.S. Department of Commerce  
National Technical Information Service

**NTIS**

EPA/600/D-88/182  
August 1988

FLEX -- AN EXPERT SYSTEM TO ASSESS  
FLEXIBLE MEMBRANE LINER MATERIALS

Robert E. Landreth

RISK REDUCTION ENGINEERING LABORATORY  
OFFICE OF RESEARCH AND DEVELOPMENT  
U.S. ENVIRONMENTAL PROTECTION AGENCY  
CINCINNATI, OH 45268

REPRODUCED BY  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
U.S. DEPARTMENT OF COMMERCE  
SPRINGFIELD, VA 22161

| TECHNICAL REPORT DATA<br>(Please read Instructions on the reverse before completing)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                  |                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|---------------------------------------------|
| 1. REPORT NO.<br>EPA/600/D-88/182                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 2.                                               | 3. RECIPIENT'S ACCESSION NO.<br>PB88-244578 |
| 4. TITLE AND SUBTITLE<br>Flex -- An Expert System to Assess Flexible Membrane Liner Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                  | 5. REPORT DATE<br>August 1988               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                  | 6. PERFORMING ORGANIZATION CODE             |
| 7. AUTHOR(S)<br>Robert E. Landreth                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                  | 8. PERFORMING ORGANIZATION REPORT NO.       |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>U.S. Environmental Protection Agency<br>26 W. Martin Luther King Drive<br>Cincinnati, OH 45268                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                  | 10. PROGRAM ELEMENT NO.                     |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                  | 11. CONTRACT/GRANT NO.                      |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Risk Reduction Engineering Laboratory<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Cincinnati, OH 45268                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                  | 13. TYPE OF REPORT AND PERIOD COVERED       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                  | 14. SPONSORING AGENCY CODE<br>EPA/600/14    |
| 15. SUPPLEMENTARY NOTES<br>Robert E. Landreth 513/569-7836                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                  |                                             |
| 16. ABSTRACT<br><br><p>The Hazardous and Solid Waste Amendments of 1984 required the use of flexible membrane liners (FML) that are chemically compatible with the waste and leachates that are to be contained. The FML design requirements can be partially satisfied by using the Test Method 9090 for compatibility and analyzing the results. Method 9090 is difficult to run, and experts are required to review and interpret the resulting data to determine chemical compatibility.</p> <p>The USEPA's Office of Research and Development has developed a computerized expert system to assist permit writers in reviewing chemical compatibility data for hazardous waste treatment, storage and disposal facilities.</p> <p>This paper will describe the development of the expert system, the Beta testing to verify the system, experiences with using the system, and its availability.</p> |                                                  |                                             |
| KEY WORDS AND DOCUMENT ANALYSIS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                  |                                             |
| 17. DESCRIPTORS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | b. IDENTIFIERS/OPEN ENDED TERMS                  | c. COSATI Field/Group                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                  |                                             |
| 18. DISTRIBUTION STATEMENT<br>Release to Public                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 19. SECURITY CLASS (This Report)<br>Unclassified | 21. NO. OF PAGES<br>15                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 20. SECURITY CLASS (This page)<br>Unclassified   | 22. PRICE<br>A03 12.95                      |

# NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# FLEX -- AN EXPERT SYSTEM TO ASSESS FLEXIBLE MEMBRANE LINER MATERIALS

Robert E. Landreth

## INTRODUCTION

When a landfill or lagoon site is proposed, the U.S. Environmental Protection Agency (EPA) requires the party seeking the permit to submit evidence that the proposed site will not cause damage to the surrounding environment. To protect the soil and groundwater beneath and adjacent to the site, flexible membrane liners (FML) have been determined to meet the Agency's liquids management strategy. Since there are wide variations in the quality of leachates from waste management sites and a wide variety of candidate liners, part of the proposal package must include data that will allow the EPA or state permit reviewer to judge the suitability of the proposed FML material. Will the FML be chemically resistant to the anticipated wastes and leachates at that particular site?

To demonstrate the chemical resistance of the FML, EPA requires that its Method 9090 be used, as a minimum, to test chemical resistance. In the test, the physical properties of FML specimens that have been immersed in waste/leachate (at 25°C and 50°C) are measured after each of four successive months and compared with the original unexposed FML physical properties. These results are included in the application for a permit to install and operate the site, and the EPA or state permit reviewer employs them to assess whether the proposed FML material will be chemically resistant.

The decision of FML suitability is complex, requiring knowledge of chemistry, polymer science, waste site construction, etc. Because a less complex decision-making process was needed for chemical compatibility determinations, EPA developed a computerized expert system--one that would embody the best thinking of recognized experts in this field. Three materials were selected for inclusion in the system: polyvinyl chloride (PVC), chlorosulphonated polyethylene (CSPE), and high density polyethylene (HDPE).

To that end, FML experts at liner fabrication firms, liner material suppliers, and an independent consultant were interviewed. What measures would these experts use and what was their rationale to evaluate the chemical resistance of the proposed liner material? Their rationale became the criteria or rule base for chemical resistance measurements that were expressed in the form of IF---THEN statements of a computer program on an IBM-PC-AT employing sophisticated system shell based on the science of artificial intelligence.

The result is the Flexible Liners Expert system: The FLEX system for evaluating chemical resistance data of FML's. Unlike conventional computer software which produces numeric results, the results of an analysis by the FLEX system are presented in a written textual report generated as the system runs. This report lists problems with the data (too scattered or missing) as well as any values that indicate that the liner may be substandard or incompatible with the immersion medium. Also included in this report are explanations as to why any data are deficient. The report may therefore be useful to a Method 9090 test reviewer to confirm a decision IF the review concurs with the rationale proposed by the FLEX system.

It should be noted that the program is designed to PROVIDE ASSISTANCE to those responsible for evaluation of Method 9090 test results. Under no circumstances should the recommendations of FLEX be considered absolute; especially when the FLEX system finds no problems with the test results. FLEX is not a substitute for a review of the test results by a skilled professional. Rather, FLEX is a screening tool to be used by those familiar with flexible membrane liner testing and EPA Method 9090. The system can rapidly pinpoint inconsistencies in the test data and test results that suggest the liner is substandard or incompatible. In this capacity, FLEX can save time, reduce oversights, and enhance the consistency of Method 9090 test reviews.

#### THE COMPARISON TESTING

To test the validity of the FLEX advisory system, five recognized FML experts evaluated sample data sets for three types of FML's--data sets similar to those produced by EPA Method 9090 (Table 1).

The 14 different sample sets of the three types of liner materials included data measurements of properties used to judge the chemical resistance of FML liners: unexposed specimens and exposed specimens measured at 25°C and 50°C for each of 4 months. Common to all 14 samples were percent-change measurements for weight, 100% modulus, and elongation at break. Each sample set did not include data for all the properties (Table 2). This lack of submitted data was typical before Agency policy established which data were required.

At least two experts analyzed each type of FML (Table 3).

The experts were asked to review each assigned data set and conclude that

- ° the results indicate that the liner material is not resistant to the chemical/waste (not resistant), or

- ° there are no results that indicate the liner material is not resistant to the chemical/waste\* (no indication not resistant), or
- ° data are insufficient to reach a conclusion (data missing), or
- ° data are inconsistent (scattered).

---

\*This statement does not say that the liner material is resistant.

Table 1. Immersion-test data sets for three flexible membrane liners\*

| Sample FML                     | Abbreviation | No. of data sets | Temperature <sup>+</sup> of samples reviewed |
|--------------------------------|--------------|------------------|----------------------------------------------|
| High-density polyethylene      | HDPE         | 6                | 25°C & 50°C                                  |
| Polyvinyl chloride             | PVC          | 4                | 25°C & 50°C                                  |
| Chlorosulphonated polyethylene | CSPE         | 4                | 25°C & 50°C                                  |

\*The data were not those of an actual Method 9090 test.

<sup>+</sup>The data for both 25°C and 50°C were submitted for each of the three FML's.

Table 2. Properties used to judge chemical resistance of three FML's; all properties not tested for each FML.

| Property                  | Unit of measurement, % change | HDPE | PVC            | CSPE           |
|---------------------------|-------------------------------|------|----------------|----------------|
| Weight                    | gram                          | x*   | x <sup>+</sup> | x <sup>#</sup> |
| Tensile strength at yield | psi                           | x*   | -              | -              |
| Elongation at yield       | %                             | x*   | -              | -              |
| 100% modulus              | psi                           | x*   | x <sup>+</sup> | x <sup>#</sup> |
| Breaking strength         | psi                           | x*   | -              | x <sup>#</sup> |
| Elongation at break       | %                             | x*   | x <sup>+</sup> | x <sup>#</sup> |
| Length                    | inch                          | x    | x              | -              |
| Width                     | inch                          | x    | -              | -              |
| Puncture strength         | pound                         | x    | x              | -              |
| Tensile strength at break | psi                           | -    | x <sup>+</sup> | -              |
| Tear strength             | psi                           | -    | x <sup>+</sup> | x <sup>#</sup> |
| Hardness                  | B-2                           | -    | x              | -              |
| Thickness                 | inch                          | -    | x              | -              |

\* All HDPE FML samples were tested for this property.

<sup>+</sup> All PVC FML samples were tested for this property.

<sup>#</sup> All CSPE FML samples were tested for this property.

x Tests conducted.

- Tests not conducted.

Table 3. Expert and FML analyzed

| Expert | HDPE | PVC | CSPE |
|--------|------|-----|------|
| FLEX   | x    | x   | x    |
| A      | x    | x   | x    |
| B      | x    | -   | -    |
| C      | -    | x   | -    |
| D      | -    | -   | x    |
| E      | -    | -   | x    |

<sup>x</sup>Sample analyzed.

<sup>-</sup>Sample not analyzed.

For each conclusion, the expert was asked to give the reason for the conclusion, state which test results were the most or least important in reaching the conclusion, draw trend lines or graphical exhibits of data provided with the data, and state how the data at 25°C and 50°C were used. In addition, if the conclusion was that there were insufficient data, the expert was to describe what additional data would be needed to reach a conclusion, and if there were inconsistencies in the data, the expert was to identify and describe how the inconsistencies could be worked around to reach a conclusion.

## RESULTS

To judge the validity and limitations of the FLEX system and to identify where it can be improved, the conclusions and reasonings of the experts were compared with those of the system. In Tables 4, 5, and 6, the areas of agreement and disagreement between the FLEX system and the FML experts are noted for the three types of FML's.

There was good agreement between FLEX and Expert A for all three liner materials; there was less agreement between FLEX and the other experts. Generally FLEX and Expert A were more apt to find the FML "not resistant" than were the other experts, although the reasoning behind FLEX and Expert A's conclusions sometimes differed. Experts B through E applied less stringent criteria to the data, were more willing to judge inconclusive data in favor of "no indication not resistant," and, in some cases, judged test results considered important by FLEX and Expert A as outliers. The experts generally agreed about which properties were the most significant in judging chemical resistance: weight change and 100% modulus (Table 7).

## CONCLUSIONS

The comparison of the FLEX conclusions with those of the experts demonstrates the feasibility and practicality of FLEX. FLEX is able to advise concerning the FML chemical resistance of data submitted as part of a permit application.

The system can be characterized as conservative--more stringent in its criteria than were some of the experts. Where FLEX and the experts disagreed, the system more often found the FML not resistant whereas the experts judged the data as being missing or with no indication not resistant. The system is presently useful to guide the permit reviewer and to identify those parts of the permit application where a more in-depth investigation is needed.

## WHAT NEXT?

Information gaps do exist; the dependence of the results on time, data trend analysis, and the relative importance of data stabilization need investigation. The need to test FML at two temperatures should also be investigated.

To further refine FLEX, the system should be reevaluated with the use of more data sets and with insights gained from the experts' analyses. The precision and accuracy of Method 9090 data should be examined. Should there be different criteria for different liner materials? for judging when physical properties have stabilized? Has the composition of the waste/leachate in the test cell remained constant during the exposure period? What are the consequences of the

Table 4. Agreement/disagreement among FLEX and FML experts concerning HDPE (at 25°C)

| Liner  | Not resistant | Data missing | Scattered/<br>conflicting data | No indication not resistant |
|--------|---------------|--------------|--------------------------------|-----------------------------|
| 80 mil |               |              |                                |                             |
| HH.8   | FLEX-A-B*     | -            | -                              | -                           |
| HI.8   | FLEX-A        | -            | -                              | B                           |
| HJ.8   | -             | FLEX-A       | FLEX                           | B                           |
| HK.8   | FLEX-A        | B            | -                              | -                           |
| 60 mil |               |              |                                |                             |
| HL.6   | FLEX-A        | -            | -                              | B                           |
| HM.6   | -             | FLEX-A       | FLEX                           | FLEX-B                      |

\*FLEX is the computer system; A and B are two experts.

Table 5. Agreement/disagreement among FLEX and FML experts concerning PVC (at 25°C)

| Liner | Not resistant | Data missing | Scattered/<br>conflicting data | No indication not resistant |
|-------|---------------|--------------|--------------------------------|-----------------------------|
| PP.3  | FLEX-A*       | -            | -                              | C                           |
| PQ.3  | A             | A            | -                              | FLEX-A-C                    |
| PR.3  | FLEX-A        | A            | A                              | C                           |
| PS.3  | FLEX-A        | -            | -                              | C                           |

\*FLEX is the computer system; A and C are two experts.

Table 5. Agreement/disagreement among FLEX and FML experts concerning PVC (at 25°C)

| Liner | Not resistant | Data missing | Scattered/<br>conflicting data | No indication not resistant |
|-------|---------------|--------------|--------------------------------|-----------------------------|
| PP.3  | FLEX-A*       | -            | -                              | C                           |
| PQ.3  | A             | A            | -                              | FLEX-A-C                    |
| PR.3  | FLEX-A        | A            | A                              | C                           |
| PS.3  | FLEX-A        | -            | -                              | C                           |

\*FLEX is the computer system; A and C are two experts.

Table 6. Agreement/disagreement among FLEX and FML experts concerning CSPE (at 25°C and 50°C)

| Liner | C°  | Not resistant | Data missing | Scattered/<br>conflicting data | No indication not resistant |
|-------|-----|---------------|--------------|--------------------------------|-----------------------------|
| CC.3  | 25° | -             | -            | -                              | FLEX-A-D-E                  |
| CC.3  | 50° | FLEX-A-E      | -            | -                              | D                           |
| CD.3  | 25° | FLEX-A        | -            | -                              | D-E                         |
| CD.3  | 50° | FLEX-A        | -            | -                              | D-E                         |
| CE.3  | 25° | FLEX-A-D      | -            | -                              | E                           |
| CE.3  | 50° | FLEX-A-D      | -            | -                              | E                           |
| CF.3  | 25° | FLEX-A-D      | -            | -                              | E                           |
| CF.3  | 50° | FLEX-A-D-E    | -            | -                              | -                           |

\*FLEX is the computer system; A, D, and E are three experts.

Table 7. Relative importance\* of properties (test results) to the experts-judging the chemical resistance of FML materials

| Property                  | HDPE  |       | PVC |   | CSPE  |   |
|---------------------------|-------|-------|-----|---|-------|---|
|                           | A     | B     | A   | C | A     | E |
| Weight                    | 1     | 1     | 1   | 2 | 1     | 1 |
| 100% modulus              | 2     | 2     | 2   | 5 | 3     | 2 |
| Tensile strength at break | least | 4     | -   | 3 | least | - |
| Elongation at break       | least | -     | -   | 1 | least | - |
| Tensile strength at yield | 3     | 3     | -   | - | -     | - |
| Elongation at yield       | 4     | least | 3   | - | -     | - |
| Puncture                  | 5     | -     | -   | 6 | -     | - |
| Tear                      | -     | -     | 3   | 4 | -     | - |
| Length                    | -     | -     | -   | 7 | -     | - |

\*1 is most important; 7 is least important.

loss of volatile solvents? Shouldn't the format of Method 9090 be the same as that of the FLEX system, with similar units used to express similar results? These questions should be resolved.

Part of the answer to these questions can be addressed in a good laboratory quality control-quality assurance program. The development of a QA/QC program will at least identify shortcomings at the laboratory level. When data are submitted from an individual laboratory, at least the Agency will have some understanding of the data quality.

#### AVAILABILITY

The Agency is currently reviewing the FLEX Program to determine if it is consistent with policy. The Office of Research and Development is also working with selected Regional Offices for final Beta testing and to determine the utility of the system. It is intended to make the program generally available to the EPA Regional Offices and authorized states.